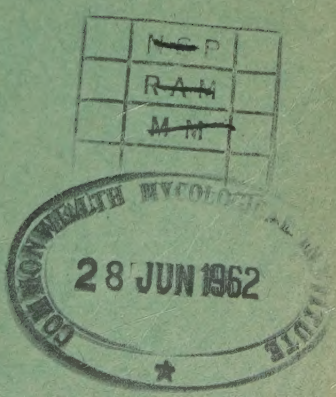
ANNUAL REPORT

of the

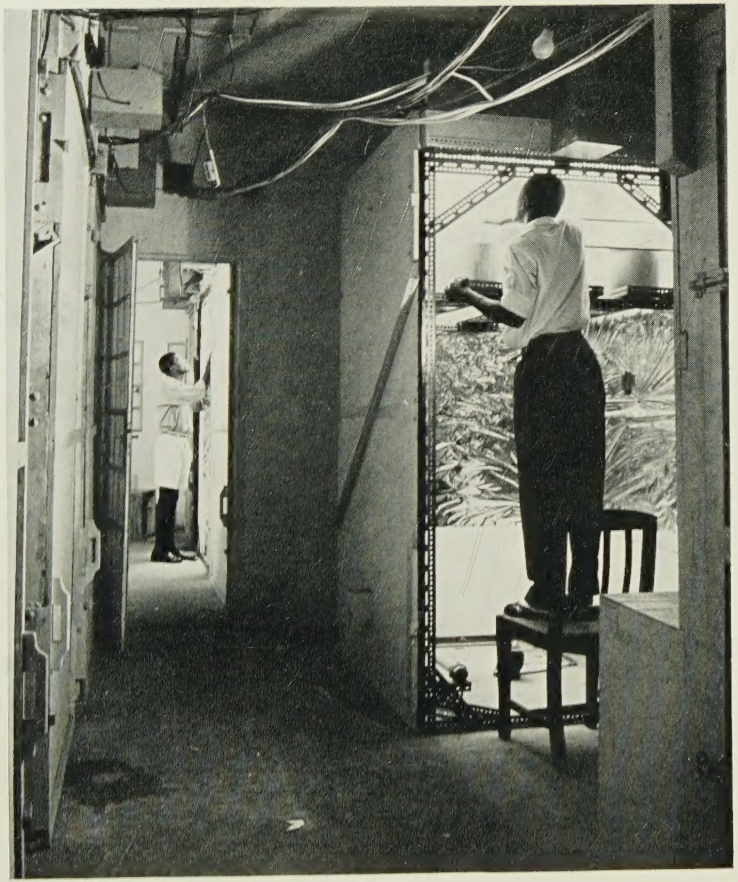
WEST AFRICAN RICE RESEARCH STATION

1960



Digitized by the Internet Archive
in 2025

https://archive.org/details/annual-report-west-african-rice-research_1960



WEST AFRICAN RICE RESEARCH STATION

The growth cabinets: general view

The control panel

ANNUAL REPORT

of the

WEST AFRICAN RICE RESEARCH STATION

1960

Price 2/-

Published on behalf of the
West African Rice Research Station, Rokupr, Sierra Leone,
by the
Crown Agents for Oversea Governments and Administrations,
4 Millbank, London, S.W.1
1962

To be purchased from either of the two agencies overleaf and from the Government Printing Department, Freetown, Sierra Leone.

A POISONOUS INSECTICIDAL SOLUTION HAS BEEN USED IN BINDING THIS BOOK

Printed by Eyre and Spottiswoode Limited
Her Majesty's Printers
at The Thanet Press, Margate

ADMINISTERING AUTHORITY

THE SIERRA LEONE GOVERNMENT

Director of Agriculture:
J. M. DENT, B.S.C., A.I.C.T.A.

ADMINISTRATIVE AND PROFESSIONAL STAFF

At 31st March, 1961

Officer in Charge:
H. D. JORDAN, O.B.E., B.SC., A.R.C.S., A.I.C.T.A.

Botanists:
E. H. ROBERTS, B.SC., PH.D.
R. Q. CRAUFURD, B.SC.
A. J. CARPENTER, M.A., DIP.AGRIC.SCI.

Soil Chemists:
P. R. HESSE, B.SC., PH.D., F.R.I.C.
J. W. O. JEFFERY, B.SC., A.R.I.C.

Soil Microbiologist:
M. G. R. HART, B.SC., PH.D.

Station Management:
R. A. BOHUN, B.SC., D.T.A.

FOREWORD

by

HIS EXCELLENCY
SIR MAURICE DORMAN, K.C.M.G.
Governor-General of Sierra Leone

I write as a layman and as a non-scientist. Much of the technical work recorded in the Annual Report of the West African Rice Research Station, which we in Sierra Leone familiarly call Rokupr, does not mean as much to me as to professional scientists. But this I do know, and of this I am fully convinced from frequent visits to Rokupr over a number of years—the work of Rokupr is of outstanding quality and of vital importance. Its work is of direct importance both to those parts of West Africa where rice is already grown as a staple food as in Sierra Leone, and to other areas where it would be an acceptable alternative foodstuff—all West Africans like rice. But in some fields of research Rokupr's activities are ahead of almost all others and are therefore of potential importance throughout the world.

When I visit Rokupr I am always struck by the keen quality of the men working there, and the practical effectiveness of the results of their research. Increased yields in Sierra Leone are already resulting from Rokupr's activities. New lands previously unusable are growing rice. Problems of how to bring large acreages of riverain lands and mangrove soils into immediate production are understood, and provide the basis of knowledge on which increased production of a basic foodstuff can be confidently planned, not only in this country but in others in West Africa.

It was with great pleasure that I accepted the invitation to write a foreword to this Annual Report because those concerned with increasing the world's production of staple foods should know about the outstanding work being done in this field at Rokupr.

CONTENTS

	Page
INTRODUCTION	9
ADMINISTRATION	
Staff	10
Publications	11
Touring and Visits	12
Visitors	12
MANAGEMENT AND MAINTENANCE	13
WEATHER	14
AGRONOMY	14
BOTANICAL RESEARCH	17
Introduction and Testing	17
Promising Varieties	17
Milling Experiments	20
Selection	21
Hybridization	21
Physiological Work	23
Factors influencing duration	24
Dormancy and Viability	25
Possibility of nitrogen fixation	26
Diseases	26
SOIL SCIENCE	27
Oxidation of sulphur compounds	27
Experiments on mangrove soils	29
Implications of Reclamation	29
Phosphorus fixation	30
Nigerian Swamp Soils	31
Chemistry and fertility of rice soils	32
APPENDIX A	
Meteorological Records	34
APPENDIX B	
Results of fertilizer Trials	35

INTRODUCTION

The background to rice growing in West Africa and, more specifically, some development schemes and their problems have been discussed in the Introductions to previous Annual Reports. In this year's Introduction attention will be focussed in more detail on one aspect of the relation of the rice plant to its environment—that of the effects of light and temperature on growth and yields.

The genetic constitution of any plant determines its potential yield. This yield can however only be attained under optimum environmental conditions. There must, for example, be a sufficiency of nutrients in the soil, adequate water and suitable conditions of light and temperature for development and photosynthesis. In addition, for those plants whose yield depends on their flowering and fruiting, the conditions must be suitable for the correct regulating of the growth of the plant and the due change from vegetative growth to the reproductive stage. Different plants differ in their sensitivity to these factors and the less sensitive they are the more adaptable to a range of conditions they are. On the other hand the highest yielding plants obtained by breeding have often been very specific in their requirements. There is inherently no reason however why adaptable plants should not give as high yields as less adaptable ones and that they have not is due mainly to the techniques of breeding and selection generally used in the past.

Rice has always been considered to be very specific in its requirements and the multiplicity of varieties grown in the main rice-producing countries of the world bear witness to this. However it is generally agreed that the number of varieties cultivated bears no relation to the number which would be necessary to obtain maximum yield. There is at present a general move to reduce the total of varieties in cultivation and thus bring policies into line with those successfully adopted for other important cereals, the advantages of which are manifest. At Rokupr, it has always been our practice to keep the number of recommended varieties to a minimum, and experience thus obtained has shown that considerable adaptability in many respects is to be found in various pure lines of rice. Apart from specific extreme conditions—e.g. deep-flooding areas which need floating rices—our improvement programme has been designed to give full weight to the property of adaptability; trials are therefore carried out under a range of conditions and in different seasons before new varieties are selected for release.

For proper consideration in this work it is however necessary to define more closely the conditions for which adaptability is sought. Among the factors controlling the growth of the plant are some, such as nutrient supply, where control of the environment is more easily carried out and the character does not therefore assume such an importance. The control of light and temperature is however much more difficult, though control of light intensity is carried out with some perennial crops by shading. Adaptability of rice to a range of light durations and intensities and temperatures therefore assumes particular importance, especially since within the area of West Africa, stretching as it does over twelve degrees of latitude, there is considerable variation in day-length, amount of insolation, and both day and night temperatures.

The effects of light and temperature on plant growth have been studied intensively in many plant species. It is known that growth-rate and accumulation of food-reserves are affected by the amount of light radiation and temperature, that day-length affects the time of flowering and yield, and that the response to day-length may be altered by temperature. Knowledge of these problems is however far from complete and this applies particularly to rice, although a considerable amount of work has been carried out on this crop—enough to show that these factors are very important, especially in tropical varieties. Work on this station has shown for instance that a delay of eight weeks in planting can cause a considerable alteration in the period from sowing to harvest and this may be associated with an alteration in yield of over 500 lbs. per acre: the evidence suggests that the main effect is due to sensitivity to day-length. But much of the work on rice has been carried out under conditions which have not been closely controlled and at present it is impossible to interpret many of the results unambiguously.

Our current breeding programme includes selection of varieties insensitive to photoperiod and whose wider adaptability therefore allows them to be grown out of season but, for a completely satisfactory programme to be arranged, considerably more knowledge of the effects of all light and temperature factors is needed. In order to obtain this information a series of growth cabinets have been built and are now in use. By the use of these, with controlled light and temperature, it should be possible to examine the effects of a considerable range of conditions in great detail and determine the ways in which varieties differ in their responses. The knowledge of rice growth and yield in a series of controlled environments thus obtained will be used in the breeding programme towards the aim of producing rice varieties adaptable in the field and capable of giving of their best yields under a range of light and temperature conditions and at all seasons of sowing.

ADMINISTRATION

Details in this section of the report cover the financial year, April 1960 to March 1961.

STAFF

Administrative and Professional

Mr. H. D. Jordan, Officer-in-Charge, returned from leave at the beginning of May.

Mr. A. J. Carpenter, Plant Breeder, went on leave at the beginning of June and returned in early December, Mr. J. W. O. Jeffery, Soil Chemist, was on leave from mid August to the beginning of January, and Dr. P. R. Hesse, Soil Chemist, went on leave in mid March.

Dr. E. H. Roberts, Plant Physiologist, Mr. R. Q. Craufurd, Plant Breeder, and Dr. M. G. R. Hart, Soil Microbiologist, were in post for the whole of the year.

Mr. R. A. Bohun, of the Sierra Leone Department of Agriculture, arrived to fill the post of Station Manager in the latter part of August.

Mr. E. E. Harris, Executive Officer, arrived at Rokupr in the middle of December.

Mrs. Enid M. Jeffery and, during her absence on leave, Mrs. Dorothy L. Roberts have continued to assist in the library.

Clerical and Technical

With the arrival of an Executive Officer, the post of First Grade Clerk has been superseded. The establishment thus consists of one Second Grade and three Third Grade Clerks, a Library Clerk and a Store Clerk. Of these, only one Third Grade and the Store Clerk are available, the other positions being filled with temporary clerical assistants.

One Laboratory Assistant resigned in September and the vacancy remains unfilled.

The field staff position continues to remain satisfactory.

A week's course in identification of standard rice varieties, rogueing in the field and purity testing was given to field staff of the Sierra Leone Department of Agriculture.

Unestablished staff and Labour

There is no difficulty in recruiting to these grades and minor employees remain at full strength. The labour force averaged 110 throughout the year.

PUBLICATIONS

The 1959 Annual Report was unfortunately rather delayed and had not been received back from the printer by the end of the year.

Brief Quarterly Progress Reports continued to be issued and one Periodic Scientific Report—No. 11—dealing with breakage of rice during milling was prepared and circulated.

The following papers have been published:—

"Defining the State of Reduction of a Paddy Soil", J. W. O. Jeffery, Journal of Soil Science, **12.** 1, 172-179. (1961).

"Possibility of Fixation of Atmospheric Nitrogen by the Rice Plant", M. G. R. Hart and E. H. Roberts, Nature, **189.** 589. (1961).

The following papers have been submitted for publication:—

"Viability of Cereal Seed for Brief and Extended Periods", E. H. Roberts, Annals of Botany N. S., 1961.

"The Viability of Rice Seed in relation to Temperature, Moisture Content and Gaseous Environment", E. H. Roberts, Annals of Botany N.S., 1961.

"Dormancy in Rice Seed. I. The Distribution of Dormancy Periods", E. H. Roberts, Journal of Experimental Botany, 1961.

"Dormancy in Rice Seed. II. The Influence of Covering Structures", E. H. Roberts, Journal of Experimental Botany, 1961.

"Dormancy in Rice Seed. III. The Influence of Temperature, Moisture and Gaseous Environment", E. H. Roberts, Journal of Experimental Botany, 1962.

"Some Useful Techniques in speeding up Rice Breeding Programmes", A. J. Carpenter and E. H. Roberts, Empire Journal of Experimental Agriculture, 1962.

"Estimation of Percentage Natural Cross-pollination: Experiments on Rice", E. H. Roberts, R. Q. Craufurd and F. LeCochec, Nature, 1961.

"Moisture Changes in Raw Paddy and Parboiled Paddy in West Africa and their influence upon Milling Quality. I. Moisture Changes in the Ripening Crop", R. Q. Craufurd, Empire Journal of Experimental Agriculture, 1962.

"Moisture Changes in Raw Paddy and Parboiled Paddy in West Africa and their influence upon Milling Quality. II. Changes during drying", R. Q. Craufurd, Empire Journal of Experimental Agriculture, 1962.

"Some Differences between the Soils of Rhizophora and Avicennia Mangrove Swamps in Sierra Leone", P. R. Hesse, Plant and Soil, July 1961.

"The Decomposition of Organic Matter in Mangrove Swamp Soil", P. R. Hesse, Plant and Soil, May 1961.

"Phosphorus Fixation in Mangrove Swamp Muds", P. R. Hesse, Nature, 1961.

"Measuring the State of Reduction of a Waterlogged Soil", J. W. O. Jeffery, Journal of Soil Science, September 1961.

"A Turbidimetric Method for the Determination of Elemental Sulphur", M. G. R. Hart, Analyst, July 1961.

"The West African Rice Research Station", H. D. Jordan, Nature, May 1961.

TOURING AND VISITS

Dr. Hesse visited Nigeria from the end of October to the beginning of December. He toured the Niger delta areas of both the Eastern and Western Regions and made brief visits to the Federal Rice Research Station at Badeggi and the Northern Region Research Station at Samaru.

Station extension areas at Mandu, Kontobe, Torma Bum and Wellington received regular visits throughout the year.

VISITORS

His Excellency Sir Maurice Dorman, K.C.M.G., Governor of Sierra Leone, and Lady Dorman, accompanied by Dr. and Mrs. H. Dorman, visited the station towards the end of January. Mr. A. F. F. P. Newns, when acting as Governor, made a visit in April. He was accompanied by Mrs. Newns and by the Honourable Mahmoud Ahmed, acting Minister of Internal Affairs and Development.

The Prime Minister of Sierra Leone, Sir Milton Margai, Kt., M.B.E., paid a brief call at the station in August, as did the Honourable Albert Margai, Minister of Natural Resources of the Sierra Leone Government, in November.

Visitors from the United Kingdom included Messrs. E. T. Burtt and J. L. Crosby of Durham University in May, L. Horton of the Tropical Products Institute in June, J. Haines of Plant Protection Ltd. in September, H. A. Marquand, J. K. Cordeaux and M. McLaren, Members of the United Kingdom Parliament, in December, and H. M. Swanzy of the British Broadcasting Corporation in January. The last named was accompanied by Mr. John Akar, Director of Broadcasting in Sierra Leone, and recordings were taken for use in local and United Kingdom broadcasts.

From other overseas countries came Messrs. N. Heseltine of the Food and Agriculture Organization of the United Nations, and F. J. Simmonds, Director of the Commonwealth Bureau of Biological Control, in June, and Dr. Parthasarathy, Rice Expert of the Food and Agriculture Organization, in August.

The Station Committee met at Rokupr in mid March. Mr. J. F. G. Sykes, Administrator of the West African Research Office, was in the chair; Nigeria was represented by Mr. J. E. Y. Hardcastle, Ghana by Mr. C. A. Dadey, Gambia by Mr. J. A. Austin and Sierra Leone by Messrs. D. G. Reid and J. M. Dent.

Other visitors from West Africa included Dr. J. S. Robertson of the West African Institute for Oil palm Research in April, Messrs. A. Nobre de Viega and R. Alves da Silva of the Agricultural Services of Portuguese Guinea in May, Mr. D. L. Downie, Deputy Director of the West African

Institute for Oil palm Research in August, Messrs. H. A. A. M. Wirtz, Food and Agriculture Organization Rice Expert and M. Fofana, Director of Production at Forecariah from the Republic of Guinea in November, and a delegation from the Guinea Government consisting of Messrs. Maki Kouyate, Mamadou Tounkara, Maurice Besse and Khalidou Diallo in December.

MANAGEMENT AND MAINTENANCE

LAND

A part of the new area of swamp land was put under cultivation this year and after harvest a start was made on laying it out with drains and access bunds.

BUILDINGS

Air conditioning has been installed in the laboratories and library. By inter-connecting ducts it has been found possible to extend it to most of the laboratories and this should lead to considerably less trouble with electrical equipment which in the past has frequently become unserviceable due to high humidities. Some modifications in layout have also been made in the Soils laboratories.

The conversion of a small office building into a laboratory for growing rice under controlled conditions has been completed.

Modifications to one of the professional quarters have been started and the two Rest Houses have been completely overhauled and redecorated.

The deep water tank has been repainted and extension of the main drying floor begun.

SERVICES

The filter system installed in the main water supply was of indifferent effect in curing the trouble of dirty water in the dry season. However, by careful management of the scour valve to the dam, a great improvement has been obtained though the water is still very discoloured in the latter part of the dry season.

The electricity supply has remained reasonably satisfactory despite considerable fluctuations in voltage and frequency.

VEHICLES AND MACHINERY

The new Bedford 30-cwt. lorry gave good service throughout the year as did the Land Rover. The latter, which is now due for replacement, had however a number of breakdowns.

Dry rot was found seriously to have affected the decking and timbers of the launch and this has had to undergo an extensive overhaul and repair and has therefore been out of action for a major part of the year.

The Ferguson tractor also had some breakdowns but has been in heavy use with trailor and gang mower. The M.G.6. tractor is undergoing complete overhaul.

STATION UPKEEP

Repairs have been made to the tarred stretches of the station roads, and the upland boundary between the station and the town has been cleared and prepared for fencing.

Seed from the Angola Oil Palm plantation continues to be made available to the Sierra Leone Department of Agriculture.

Some further thinning of trees has been carried out.

EXTENSION AREAS

Station extension areas continue to number four as detailed in the last report. At Mando, Kontobe and Torma Bum, trials continue to be carried out on different types of riverain grasslands. At Wellington, on freshly empoldered mangrove land, the soils have been under observation and frequent samples have been taken for examination.

In addition to these four areas, a small piece of upland regrowth bush a few miles away from the main station was utilized temporarily for upland rices.

WEATHER

Weather this year has been very much on the average pattern except for slightly more sunshine than usual, and the period of maximum rainfall being rather more spread. The dry season was well defined and severe, the first rain of any magnitude falling on the last day of April. There were only insignificant amounts of rain after mid November. Full meteorological records for the year are given in Appendix A.

AGRONOMY

Field procedure continues on the general lines described last year. A number of small agronomic experiments were however laid down to check on existing practice and to confirm published results from other countries.

An unreplicated trial tested the effect of fertilizer applied at different stages of growth of the plant. Three sowing dates were used but all gave similar results and those shown in Table 1 are for one sowing date only. The highest yield was obtained when fertilizer was applied at the time of initiation of flower primordia. This agrees with results obtained elsewhere.

TABLE 1

Time of application of fertilizers

Variety Lead 35.
Plots 8 × 8 feet single plants planted at measured 6 inch spacing.
Fertilizer applied at 2 cwt. acre of 1:2:1 mixture of sulphate of ammonia, superphosphate and sulphate of potash.
1 at planting
2 at initiation of flower primordia
3 one week before modal flowering.

Treatment	*Yield in lb./acre*	*Mean panicle weight*	*Mean number panicles/plant*	100-*grain weight*
No fertilizer	959	1·90	1·82	2·75
1	1027	1·46	2·66	2·85
2	1229	2·13	2·92	2·71
3	1019	1·74	2·28	2·78

Panicle weight and number are mean values from 25 plants.

A second unreplicated trial compared four plant densities and three spacings. This was again repeated for three sowing dates with similar results. Results from one sowing are shown in Table 2. These confirm the present practice of planting two to three plants per stand at six inch spacing.

A statistical experiment was carried out to investigate the effect on yield of leaving rice seedlings for different times in nurseries of different fertilities. Two varieties of contrasting duration were used, B.G.79 of 145 days and Radin China 4 of 180 days, but no significant difference

TABLE 2

Planting distances and densities

Variety Lead 35.
Plots 4 × 4 feet.
Spacings 3 × 3, 6 × 6, and 12 × 12 inches.
Plants per stand 1, 2, 4 and 8.

Yields in lb./acre

Spacing \ *Plants/stand*	1	2	4	8	*Mean*
3 × 3	1962	1716	1044	984	1427
6 × 6	1536	1722	1950	1476	1671
12 × 12	1296	1146	1554	1302	1324
Mean	1598	1528	1516	1254	1474

Note: The high yield of the single plants at close spacing is due largely to a high proportion of missing plants.

between the varieties were shown, nor was there any significant interaction between variety and treatment. The results, which are shown in Table 3 are therefore the mean of yields for both varieties. Fertility of nursery was chosen on the basis of observation in previous seasons and the fertility of the best was supplemented by application of compost and artificial fertilizers.

TABLE 3

Time in nursery and fertility

Layout $3^2 \times 2$ factorial with 3 replications.
Treatments 25, 45 and 65 days in nurseries at three levels of fertility.
Varieties B.G.79 and Radin China 4.
Plots 20 × 20 feet.
Area of plot harvested ·00918 acre.

Yields in lb./acre

Fertility \ *Time in days*	25	45	65	*Mean*
	Critical Difference	5%	352	*C.D.* 5% 202
		1%	475	1% 274
Low	2001	1674	1062	1576
Medium	2286	1946	1334	1855
High	2450	2178	1538	2050
Mean	2244	1931	1305	1828
	Critical Difference	5%	202	
		1%	274	

Coefficient of Variation 16·4%

The results suggest that both reduction of the nursery period and increase in nursery fertility are likely to give higher crop yields. This confirms earlier observations. When the station started, trials showed that eight weeks in the nursery gave the best yield. These nurseries were rather infertile upland nurseries. At a later stage, more fertile nurseries on the edge of the swamp were brought into use and it was found that the time in the nursery could be reduced to six weeks—which was adopted as the standard. From time to time it has been necessary to raise seedlings quickly, and it has been found that the period in the nursery could be reduced to three weeks with heavy fertilizer application.

At the time of transplanting, sub-samples of the seedlings were examined and the stage of growth as represented by leaf number and by wet weight was measured. In all cases retention of seedlings in the nursery after the fifth leaf had emerged was associated with a decline in yield, and the quicker the plant could be brought to the five-leaf stage the higher the yield. Size, as determined by the wet weight was of relatively minor importance compared with leaf number.

An investigation was started into the possibility of taking two crops each season from the swamps on the upper reaches of the Scarcies river estuary. The factors limiting this cropping régime are the onset of the rains for nursing the rice (mid May in this area) and the influx of tidal salt water as the flow of fresh water declines at the end of the rains (February to April). Developments of this experiment are planned to give reliable yield figures and comparisons for testing both photoperiod insensitive rices and salt tolerant varieties as well as investigating the purely local situation.

The trial this year has suggested that large increases in yield can be expected from this extension of the cropping season. These increases arise, not only from the second crop, but from the better performance of the first crop when planted earlier, an effect shown in previous date-of-sowing trials. The yields from the various cropping systems used this year are shown in Table 4.

TABLE 4

Double Cropping

Layout 6 × 6 Latin square.
Varieties 1st crop Radin China 4 and Faya.
2nd crop 1—Radin China 4, 2—Lead, 3—Tai Chu 65
Plots 20 × 20 feet.
Area of plot harvested ·00918 acre.

Variety	*1st Crop sown*	*Mean Yield in lb./acre*				
		1st Crop	*2nd Crop* 1	2	3	*Total season*
Radin China 4	May	3030	—	—	—	3030
Radin China 4	May	2760	—	—	490	3250
Radin China 4	Aug.	1890	—	—	—	1890
Faya	May	2760	—	620	—	3380
Faya	May	2720	1030	—	—	3760
Faya	Aug.	1830	—	—	—	1830
		Critical Difference (5%)				554
		Critical Difference (1%)				753
		Coefficient of Variation				16·1%

Farm yields have been rather variable this year, most of the more fertile areas now being used for experimental work. Under multiplication however, Faya, Radin China 4 and Toma 112 all gave yields of over 1,800 lbs. per acre, the highest yield recorded being 2,700 lbs. per acre from just under half an acre of Radin China 4. Some of the promising varieties again gave over 3,000 lbs. per acre on plots of about a twelth of an acre.

Ngasein 57, which has become impure and is under reselection, has been omitted from the Standard varieties maintained by the Genetic Stock system, which now number ten. 220 bushels (of 60 lbs. weight) of pure seed of these varieties was produced and distributed.

One further polder for irrigation from the deep water tank in the dry season was constructed. Better water control has been obtained on this polder and larger plots of 50 varieties suitable for out of season growth have been planted and are growing well.

BOTANICAL RESEARCH

The year has been one of consolidation and preparation for future work. Fewer rices have been introduced, and attention in the improvement programme has largely been on hybridization, the techniques of which have now been established. Milling experiments have continued and work on dormancy and viability completed. Preparations have been made for the investigation of light and temperature effects on growth to start in the coming year.

INTRODUCTION AND TESTING OF RICE VARIETIES

Sixteen rices were introduced from overseas during the year and added to the collection. These are as follows:—

From Malaya:	Radin Ebos 83; Engkatek; Radin Kling
From Burma:	Bommadewa; Kauklat; Kaukti; Kaukyin; Okshit (Mayin)
From Hyderabad:	MTU.17
From Congo:	Oubangui Chari
From Gambia:	Sintanediofor; Kaukau; Jappine Tunkungo; E 425; 560 A; 559 A.

Recent introductions which show no promise under West African conditions and which do not appear to have any desirable characters which warrant their retention for future hybridization have been discarded, and the West African Rice Varietal Collection, which is maintained at Rokupr, now numbers 456 varieties. Of these, 356 were grown under observation during the year and seed of the remaining 100 was maintained in the air-conditioned seed store.

A collection of 70 upland rices was grown on a typical upland farm of low fertility near the station. About a half of these were retained for further observation and selection in 1961. A statistical yield trial of nine varieties was laid down also on this land but there was considerable soil variation (Coefficient of Variation—36%) and no significant differences in yield between varieties were shown. Application of sulphate of ammonia and superphosphate was made to half of each plot and a highly significant increase in yield of 65% resulted. The mean yield however remained low (450 lb./acre) and the increase in terms of profit was negligible. No significant variety times fertilizer interaction was shown.

As in previous years requests have been received from other countries for rice varieties from the collection, and the following were sent out during the year:

To Ghana	4 samples
To Senegal	12 samples
To Mali	24 samples
To Cameroons	4 samples
To Sudan	7 samples
To Southern Rhodesia	24 samples

Promising Varieties

Most of the varieties in this collection have now been grown for at least three years and at all levels of fertility. The long narrow plots of about one-twelfth of an acre are still in use.

Yields this year were lower than last year and only two varieties gave yields over 3,000 lb. per acre; Sokotera (from Zanzibar), which gave this yield on the area of lowest fertility, and Radin Siak 34 (from Malaya). Both of these varieties have shown consistently good yields now for four years. Anak Didek (from Malaya) which had given three years' good yields has this year given an indifferent one. This variety has however become very impure and is being reselected. Cadung Phen R92 and Bong Sen Den 2R10 (both from South Viet Nam) which had given two years' good yields, were this year on the area of lowest fertility and did not do so well, though their yields were fair. Nachin 11 (from Malaya) once more gave a good yield and two other varieties which were first grown in this series in 1959, Ecombouka (from Casamance) and SR26 (from Orissa) also did well. Last year they were not outstanding but gave reasonably good yields.

Three yield trials were laid down on mangrove land at Rokupr this year. The trial of late varieties established in 1958 again failed to show any significant differences in yield, but combined analysis for the three years shows Gantang and Pai Gazo (both from North Borneo) and Raminad (from the Philippines) to have significantly higher yields than the established varieties Kav.12 and India-pa-lil 46. Milling tests showed little difference between these three varieties, but as both Pai Gazo and Raminad lodged in two years out of the three it is proposed to multiply Gantang and to release this as an alternative late variety. Details of the experiment are given in Table 5.

TABLE 5

Yield trial of Late Varieties

Layout 6 × 6 Latin square.

Plots 15 × 15 feet planted at measured 6 inch spacing 2 plants per stand.

Area of plot harvested ·00388 acre.

Variety	*Mean Yield in lb./acre*			
	1958	1959	1960	*Variety Mean*
Gantang	3437	2964	2441	2947
Pai Gazo	3301	3136	2294	2910
Raminad	3352	2975	2388	2905
Seri Raja	3142	3031	2200	2791
Kav. 12	3091	2830	2289	2737
India-pa-lil 46	2903	2969	2165	2679
Season Mean	3204	2984	2296	2828
Critical Difference (5%)	220			134
Critical Difference (1%)	303			178
Coefficient of Variation	5·7%	7·5%	8·3%	7·1%
Critical Difference Seasons (5%)				190

Of the other two trials at Rokupr only one gave any good result. This was a trial of early and medium early promising varieties. SR26 in this trial gave a highly significantly greater yield than B.G.79, with which it is comparable in duration, and than other standard varieties, while Sokotera and Haji Haroun (from Malaya) gave yields significantly greater than the standard variety Lead 35. Details are shown in Table 6.

TABLE 6

Yield trial of early Promising Varieties

Layout Randomized Block 4 replications.
Plots 10 × 10 feet planted at measured 6 inch spacing 2 plants per stand.
Area of plot harvested ·0023 acre.

Variety	*Mean Yield in lb./acre*
SR 26	4300
Sokotera	3750
Haji Haroun	3530
B.G.79	3380
Faya	3230
D 99	3200
Lead 35	2930
HR 8	2620
Critical Difference (5%)	570
Critical Difference (1%)	780
Coefficient of Variation	11·7%

Four varietal yield trials were carried out on non-mangrove land on station extension areas. At Mando—where Radin China 4 was recently released for use—a wetter site on the riverain grasslands was chosen where longer duration rices could be grown and a yield trial of such varieties laid down. No significant differences in yield were shown.

At Kontobe, on the inland riverain flood plains, a series of more intensive trials has been started, using the six varieties which had shown up best in the earlier more extensive trials. One design was used but this was repeated in three different areas; once in the deeper flooding parts and twice on the shallower flooding land near the edge of the area. One of these latter replications was irrigated with extra drainage water at the beginning and end of the season. In each of the replications Haji Haroun gave a significantly higher yield than the standard variety Toma 112 and in two out of the three Nachin 11 did also. Full details are given in Table 7. As no suitable variety has yet been recommended for this type of land,

TABLE 7

Yield trial of Early Varieties—Kontobe

Layout 6 × 6 Latin square.
Plots 10 × 10 feet broadcast at a rate of 60 lb./acre of seed. 1cwt./acre sulphate of ammonia and 1½ cwt./acre superphosphate applied.
Area harvested ·0023 acre.
Replications: I Deep flooding area.
II Shallow flooding area.
III Shallow flooding area with supplementary irrigation.

Variety	*Mean Yield in lb./acre*		
	Rep. I	*Rep. II*	*Rep. III*
Nachin 11	776	1199	1312
Haji Haroun	699	1857	649
Sokotera	304	1703	508
Radin Siak 34	337	1249	372
Parn A-191	463	440	341
Toma 112	372	785	250
Critical Difference (5%)	249	525	352
Critical Difference (1%)	410	716	480
Coefficient of Variation	41%	36%	51%

development of which is being undertaken, these two varieties are being released as an interim measure, though the trial will be repeated in following years.

An excellent experimental area for floating rices at Torma Bum on the Sewa river was prospected and observation plots of thirty-five floaters or reputed floaters were sown in April. Normal flooding on this site is from four to six feet and a peak of up to fifteen feet of slow-moving flood is experienced in August. Of the thirty-five varieties under test, eight failed and the remainder gave yields ranging from 1,000 to 3,000 lb./acre. Seven of these varieties, chosen on earlier performance on non-floating sites, were put into a statistical yield trial in the same area. Unfortunately five of these varieties were those that failed.

Two other experiments on shallow flooding sites at Torma Bum suffered from late sowing and weed growth, and were badly damaged by birds. They thus gave little useful information.

Milling Experiments

Last year two series of experiments were reported, those following the moisture content of the ripening crop and those of the effect on milling quality of different rates and methods of drying. Further investigations have been carried out in continuation of this work.

It was shown last year that internal cracking of the ripening crop occurs in Sierra Leone in the last ten days before harvest and is associated with a cycle of alternate wetting and drying of the grain. At this time of the year afternoon humidities are low and night humidities high—in particular there are often early morning mists and the panicles may often carry visible surface water. As cracking is known to occur during the remoistening stage the relative importance of high humidity and of surface water on the grain was examined in laboratory experiments. Samples of dry paddy were soaked in water for varying periods, the water drained off and the paddy stored in airtight bottles for 48 hours. Further samples were similarly soaked but then dried slowly on the artificial drier to 11 to 12 per cent moisture content before storing; this was an attempt more nearly to simulate field conditions. A third series of samples were moistened by blowing saturated air through them before storage. After the storage period the moisture content of the paddy was measured with a Marconi moisture meter and subsamples were dehusked by hand and the percentage of cracked grains counted.

When remoistened with water vapour the percentage of cracked grains remained relatively constant between 19 and 25 per cent, between moisture contents from 11·7 to 19 per cent. On the other hand when remoistened with water there were 74 per cent cracked grains at 16·4 per cent moisture content and this rose steadily to 94 per cent cracked grains at 19 per cent moisture content. The moisture content of 16·4 per cent was obtained after only one minute's soaking. When the grain was soaked and then dried however, soaking of up to five minutes had little effect—the percentage cracked grain remaining at 21. With longer periods of soaking however the percentage cracked grains increased until after one hours soaking it reached 81 per cent. These results show clearly that it is absorption of liquid water that causes cracking and that absorption of water vapour causes little if any. In the field it is the early morning mists and condensation of water on the panicle that causes the trouble.

Last year it was shown that slow artificial drying or shade drying caused less breakage when parboiled paddy was milled than quick drying or sun drying. Shade drying however took eight to sixteen hours and this is too

long a time to be practical. Since cracks do not develop until below a moisture content of 15 per cent it was thought that a combination of methods could be used, i.e. fast drying to 15 per cent followed by slow drying, and the time considerably reduced. Experiments showed however that the moisture gradient established under fast drying persisted when the change to slow drying was made, and that in order to obtain satisfactory results a resting period of two to four hours is necessary between the two stages of drying. This nullifies the saving in time.

When parboiled paddy is dried in the artificial drier at the slow rate it can in fact take a shorter time than sun drying, yet cracking does not become excessive. It is thought therefore that the temperature of drying must have some effect as well as the rate of drying. Investigation of this effect will need modification of the present drier which is designed to dry at a constant temperature with variable air-flow.

SELECTION OF IMPROVED RICES

Loss of purity has been observed in three of the promising varieties and re-selection of these has been started. Forty-three lines of Pindosein A 29-20, fifty of Anak Didek and fifty-four of Nachin 11 have been retained after laboratory examination of panicles selected in the field and these will be grown under observation next season.

The nine reselections of Ngasein 57 were under further observation this year and one was discarded. The remainder will be put into trial in the coming year.

HYBRIDIZATION

The techniques described in the 1959 Annual Report have been adopted on a large scale this season. Hybridizations are now done during the dry season, from December to June, using a dark-room to induce flowering in photoperiod sensitive varieties when the natural day-length is long. The F_1 plants are also grown in the dry season in buckets. The main crop season is thus left free for field observations, and the first segregating progenies in the F_2 generation are available for selection a year earlier than by traditional methods.

Maincrop varieties

Pure line selection has been carried out in the F_4 generation of the cross X(56)2, Bolo 108 × Ngasein 57.

The majority of the crosses in the new programme of hybridization for an improved maincrop rice of about six months duration were completed. The F_1 seed of these crosses was planted in pots during the dry season and the F_2 will be available for sowing in 1961.

Early varieties

The progenies from crosses made in 1958 between four good four-and-a-half to five month varieties were selected in the F_2 generation this year.

Selections have been made at Rokupr from segregating material of *indica* × *japonica* crosses received from Malaya. These crosses were originally carried out at the Indian Rice Research Institute under a scheme sponsored by the International Rice Commission. The results of this trial are shown in Table 8 and it is seen that there is considerable variation in yield between the selections.

TABLE 8

Yield trial with indica × japonica hybrids

Layout Balanced lattice with 4 replications.
Plots 12 × 12 feet planted at measured 6 inch spacing 2 plants per stand.
Area of plot harvested ·0033 acre.

Variety	*Mean yield in lb./acre*
52/M/6/4	1520
52/M/6/1	1470
52/M/8/1	1400
51/M/3/8	1260
51/M/4/1	1170
52/M/6/3	1120
51/M/4/2	1030
51/M/3/1	970
52/M/3/B	930
Critical difference (5%)	451
Critical difference (1%)	624
Coefficient of Variation	24%

Very early varieties

The F_2 generation of the crosses made in 1959 and grown in F_1 out of season were selected in the field. Little transgressive segregation for earliness was seen and in consequence a 110-day variety, Patnai 16, was brought into the programme as a parent and a second series of crosses was started. Two more excellent 150-day parental varieties were also brought into the programme, which now includes a range of varieties with good reported performances throughout West Africa. Selection in the field from the F_2 generation of this second series of crosses will be made in 1961.

In order to find a basis for comparing and evaluating the progeny in this programme, a yield trial of the six varieties chosen as the first parents was carried out. The results, which are given in Table 9, show that two varieties, Jhona and Tun Sart, have given significantly lower yields than the remainder.

TABLE 9

Yield trial of early parental varieties

Layout 6 × 6 Latin square.
Plots 6 × 6 feet planted at measured 6 inch spacing 2 plants per stand.
Area of plot harvested ·00083 acre.

Variety	*Mean yield in lb./acre*
B.G.79	3024
MUA 201	2986
HR 5	2659
Lati Sail	2633
Jhona	1827
Tun Sart	1827
Critical Difference (5%)	414
Critical Difference (1%)	564
Coefficient of Variation	13·8%

A yield trial was carried out during the dry season in the experimental polder with two of the *indica* × *japonica* hybrids from the crosses made in 1951, two made in India and the *japonica* variety, Tai Chu 65. One of the hybrids failed to flower but the other three gave yields highly significantly greater than Tai Chu 65. The two Indian hybrids gave yields significantly greater than the Rokupr hybrid. Details are given in Table 10.

TABLE 10

Yield trial with indica × japonica hybrids

Layout Randomized blocks 5 replications.

Plots 6 × 6 feet planted at measured 6 inch spacing 2 plants per stand.

Area of plot harvested ·00083 acre.

Variety	*Mean yield in lb./acre*
51/M/3/1 ex India	2512
51/M/4/1 ex India	2481
51/4/1/1 ex Rokupr	1785
Tai Chu 65	953
Critical difference (5%)	523
Critical difference (1%)	733
Coefficient of variation	19·6%

Floating rices

The nine strains of X(53)1, Indo-China 53 × Indo-China 24, were tested under deep flooding and gave high yields. Spaced rows were planted at Torma Bum at the end of the year for final pedigree selection in the 1961 season.

Line selection was started on the F_4 of the cross X(56)3, Toma 112 × Indo-China 53. The material shows little promise at this stage.

Interspecific hybrids

Observations have continued on F_1 material of the *sativa* × *glaberrima* cross. Attempts to produce the amphidiploid of this sterile hybrid once again failed.

PHYSIOLOGICAL WORK

The background to investigations on light and temperature effects on rice has been discussed in the introduction. The construction of the ten growth cabinets has now been completed. The policy in the design of the cabinets has been to provide the possibility of maximum adaptability of experimental design within the limitations of a relatively low capital cost, and some brief notes on the details of their construction will be of interest.

The cabinets have been designed so that light intensity, "day" length, and "night" and "day" temperature can all be controlled independently of one another. Each cabinet has a growth compartment with a floor space of 5 feet by 4 feet and a height of 7 feet 3 inches. This is separated from the lighting compartment by a sheet of 500-gauge polythene (which it is intended to replace eventually by perspex sheeting). The plants are grown in undrained 10-litre polythene buckets held on Dexion mild steel skeleton trays. Provision is made so that these trays can be moved vertically within the growth compartment so that the tops of the plants can be

maintained at a constant light intensity as they grow in height. Each tray holds five buckets and the maximum capacity of each cabinet is four trays. However, when only three trays are used it is possible to enter the cabinet and examine any plant closely without moving the buckets.

The main lighting is provided by twelve 80-watt "white" 5-feet fluorescent tubes with internal reflectors. The ceiling of the lighting compartment and the walls of the cabinet are lined with aluminized plastic in order to reduce fall-off in light intensity towards the edges. At a distance of nine inches from the ceiling of the growth compartment the main lighting provides 15,000 lux; proportionately lower intensities can be provided by switching off the appropriate number of tubes. Supplementary lighting is supplied by four 25-watt tungsten lamps in each cabinet.

Heating is provided by two 240-watt tubular heaters, four feet long, controlled by two thermostats, one for the "night" and one for the "day". Each lighting compartment is cooled by ducting the hot air out of it through the laboratory ceiling by means of an extractor fan. The air enters the lighting compartment from the growth compartment to which it is admitted through light-tight ventilators from the air-conditioned laboratory. This current of air therefore also serves to ventilate and prevent over-heating within the growth compartment. An even distribution of heat within the growth compartment is maintained by circulating the air with a mixing fan blowing upwards from the floor of the compartment. At maximum light intensity control of the temperature at 37 °C or above is possible; at lower light intensities control at lower temperatures is possible. "Night" temperatures may be controlled within the range 25 °C to 37 °C.

All the controls are centralized on one switchboard. The main lights are controlled by one time-switch operating a 3-phase relay. The supplementary lights are controlled by five time-switches which supply power to a number of sockets; the lights of each cabinet can be plugged into any of these sockets so that a large number of different combinations in the régimes of supplementary illumination are possible. The change over from "night" to "day" thermostats is also controlled by a time-switch which operates a 10-point relay.

Factors influencing Duration and Yield

It was not found possible to make the necessary arrangements this year for continuation of the successional sowing experiment at stations of different latitudes, so further work on this is in obeyance.

The successional sowing trial at Rokupr was continued for a second year, the May sowing being replaced by one in November. The same three varieties, Tai Chu 65, Lead and Radin China 4 were used. Unfortunately the integrating photometer once more failed so no records could be kept. No correlations between growth and yield and temperature were found. Full discussion of this trial awaits a third year's results.

The effect of sowing date on yield was examined in two further statistical trials. One, with the variety Radin China 4, showed no significance. The other with Lead, details of which are given in Table 11, showed that sowing on 18th June gave a significantly greater yield than earlier sowing or than sowing after 2nd July. In the three years that these trials have been carried out the highest yield in all the significant experiments has been from the 18th June sowing. And this is with three separate varieties, Lead, Radin China 4 and Faya. This sowing also gave the highest yield in the experiment this year which showed no significance, and in an unreplicated trial which was carried out with the late variety Gantang.

TABLE 11

Effect of sowing date on yield—Lead

Layout 6 × 6 Latin square.
Plots 15 × 15 feet planted at measured 6 inch spacing 2 plants per stand.
Area of plot harvested ·0038 acre.

Sowing date	*Mean yield in lb./acre*
June 18th	2308
July 2nd	2149
July 30th	1999
August 13th	1951
July 16th	1943
June 4th	1836
Critical difference (5%)	208
Critical difference (1%)	286
Coefficient of variation	8·5%

In the deep water tank this year attention was concentrated on relating performance to results in the field at Torma Bum. The thirty-five varieties grown at Torma were also grown in the tank and subjected to three flooding treatments of increasing severity, all starting at a seedling age of eight weeks. All the varieties under the most severe treatment failed; of the other two treatments all the insufficiently robust floaters exposed at Torma were killed and there was some considerable degree of correspondence between yield at Torma and vigour in the tank. Two other tank trials were unsuccessful. Considerable damage was caused by insects which cut off the leaves of the rice plants at water level.

Dormancy and Viability of Rice Seed

The main programme of work on dormancy has been completed and a summary of it was given in last year's report. The scope of the work has since been reduced and has been concerned with investigations into the mechanisms involved and the nature of the differences which exist between varieties.

The major part of the experimental programme on the viability of rice seed has also been completed. It was mentioned in the 1958 Annual Report that a critical examination of the literature on cereal seed viability had suggested that the period of viability is related in simple mathematical terms to the temperature and moisture content of the grain during storage. This has now been confirmed experimentally in rice. It has been shown that viability can be related to storage conditions in the following three ways:

1. The distribution of death points in time is Gaussian (with certain possible exceptions which are discussed more fully in one of the technical papers.)

2. The half-viability period (i.e. the time taken from harvest for half the seeds to die; this is also the same as the mean viability period of the population) is related to moisture content and temperature by the equation $\log. p = K_v - C_1 m - C_2 t$, where p = half-viability period in weeks, m = percentage moisture content, t = temperature in degrees Centigrade, and K_v, C_1 and C_2 are constants.

3. The spread of the distribution of death points in time is directly proportional to the half-viability period. This can be expressed as $\sigma = K_\sigma p$, where σ = the standard deviation of the death points in time and K_σ is a constant.

These relationships are sufficient to define the pattern of loss of viability and to predict theoretically the percentage germination after any given

period of time. The values of the constants have been calculated experimentally for the variety Toma 112 ($K_v = 5{\cdot}686$, $C_1 = 0{\cdot}159$, $C_2 = 0{\cdot}069$ and $K_\sigma = 0{\cdot}21$). These values probably illustrate the viability behaviour of a typical *indica* variety. However it is known that varietal differences do exist and work is proceeding in order to obtain some indication of the extent of these differences and to elucidate whether or not they are due to different responses to temperature and moisture content or some other factor.

It has been shown that the relationships described above may not be accurate outside the normal range of storage conditions—above 50 °C for example—and when conditions are such that the period of viability is in the order of a century. However, since extremely adverse conditions are not encountered practically, and since it has been shown that the equations tend, if anything, to underestimate viability over extremely long periods, the relationships described here can be used with confidence for designing a practical system of seed storage.

A comparison of the effects on viability has been made between hermetically sealing seeds in air, oxygen, nitrogen and carbon dioxide under a range of conditions of temperature and moisture content. The results are complex and it is evident that the influence on viability of one gas as compared with another is not necessarily the same under all régimes of temperature and moisture. When the period of viability is of the order of a year, there is evidence that storage in nitrogen may lead to an increased period of viability when compared with storage in air; this result is in general agreement with other work which has been carried out on the storage of wheat seed. It is doubtful however whether the increase due to nitrogen is sufficiently large to warrant its use as a practical measure for the storage of cereal seed.

Possibility of Fixation of Atmospheric Nitrogen by the Rice Plant

A recent report from India presented evidence which suggested that the rice plant is capable of fixing atmospheric nitrogen. If confirmed, this finding would be of great practical importance. An investigation was therefore carried out into the possibility of nitrogen fixation in the variety Lead 35 grown in hydroponics. A full report of this work has been published elsewhere but the conclusions may be summarized as follows. No evidence of nitrogen fixation was found. Using the ordinary micro-Kjeldahl method of nitrogen determination, apparent fixation occurred due to the fact that most of the nitrate—which is not detectable by the ordinary Kjeldahl method—present at the beginning of a period of nitrogen starvation was converted to substances amenable to detection by the Kjeldahl method within one week. There was therefore an increase in the Kjeldahl nitrogen over the period of nitrogen starvation. Plants grown in culture solution were found to have an unexpectedly high nitrate content compared with plants grown in the field. Thus using plants grown in hydroponics and methods of nitrogen determination which ignore nitrate, apparent fixation occurs during a period of nitrogen starvation.

DISEASES

There was not a great deal of attack by *Piricularia oryzae* in the nurseries this year, and no records were kept. The only severe attack was on some nurseries of Kav. 12, a variety known to be susceptible, which necessitated their resowing.

Ephelis pallida again occurred on the farm this year, but only to a very slight extent on the variety Lead.

SOIL SCIENCE

The work of the year has been in continuation of that reported previously and has comprised further investigations into the chemistry and microbiology of tidal soils and their reclamation for rice growing, extension and repetition of field trials on other types of rice soils and development of studies into the state of reduction of submerged soils.

INVESTIGATIONS INTO TIDAL MANGROVE SOILS

During the year the investigations into oxidation mechanisms in mangrove soils, which have been reported previously, have been continued and practical trials of reclamation procedures in the field have been started. Last year, studies in the decomposition of organic matter in the soils were also reported and this year emphasis has been placed on their phosphorus status and the effects of adding phosphorus. A further understanding of the behaviour of these soils, both in their natural state and under reclamation, is now rapidly being acquired.

Oxidation of Sulphur Compounds

The sulphur compounds found almost universally in mangrove soils and other tidal lands are: ferrous sulphide, ferrous polysulphide—probably pyrite, elemental sulphur, and sulphur in organic combination. Previous investigations have been aimed at determining the importance of these substances in the formation of acid in reclaimed mangrove soils, and have led to the conclusion that acid formation is the result of the oxidation of elemental sulphur by a bacterium, *Thiobacillus thio-oxidans*. The other substances present are not significantly attacked by this organism, though it is known from other sources that ferrous sulphide can break down rapidly by a chemical reaction and form elemental sulphur—it is thus just as susceptible to attack as elemental sulphur itself. The rôle of pyrites has been obscure. In some instances it is broken down rapidly in soil and in others it exhibits marked stability to oxidation, although its rate of breakdown is known to be catalysed by high acidities. Organic sulphur is probably of little importance in this connection as it comprises only a small fraction of the total.

One suggestion which has been made to explain the breakdown of pyrites in soil has been that, although it is stable at normal soil reaction, it breaks down rapidly when the soil acidity is increased, and that the initial increase in soil acidity will usually occur as a result of the oxidation of more reactive substances such as ferrous sulphide or elemental sulphur. The presence of ferrous sulphide is easily demonstrable by a standard analytical procedure. Examination of a number of typical tidal mangrove soils has shown that this substance is not normally present in large concentrations in soils likely to be reclaimed for rice, but occurs only in quantity in deeply flooded, reducing, marine deposits. However, previous studies using the methods then available had indicated that elemental sulphur might normally be present in large concentrations, and it was assumed that such accumulations would be responsible for acid-formation and the catalysis of pyrites-decomposition.

In order to confirm this it was necessary to evolve a satisfactory rapid method for determining the concentration of elemental sulphur present in soil, as no such method was available. A turbidimetric method has been developed, based on the solution of sulphur in acetone and its precipitation in colloidal solution by the method of exchange of solvent. A detailed description of the method has been published elsewhere. Using this method, examination of a number of soils in Sierra Leone and also some from Nigeria has shown that large concentrations of elemental

sulphur are not normally present in tidal mangrove soils unless they are partially aerated. In spite of this, acid sulphates are formed in these soils on oxidation and it must be concluded that the polysulphides present in the soil are sufficiently unstable to break down chemically under oxidizing conditions to give elemental sulphur, which may then be oxidized by the sulphur-oxidizing bacteria. Laboratory experiments and analyses of soil samples taken from the station extension area at Wellington have shown this conclusion to be correct—soil polysulphides, which comprise the bulk of the sulphur in mangrove soils, have been definitely shown to be unstable to atmospheric oxidation, even at normal soil reaction.

This result was surprising in view of the stability of pyrites which has been previously reported, as it was currently considered that the rapidity with which this substance was attacked in the field was due to the presence of more reactive substances. An understanding of the conditions under which pyrites may be oxidized and under which it may be stable was obviously essential if effective reclamation schemes were to be designed.

Rates of oxidation of both soil polysulphides and purified commercial pyrites have been studied by a method in which ferric ions were used as an oxidizing agent, and the rate of oxidation measured by the rate of release of ferrous iron. Using this method it has been possible to demonstrate that the polysulphides present in mangrove soils are not fundamentally different from purified commercial material. Obviously the apparent anomalous behaviour of these substances noted previously must be explicable in terms of the properties of the pure material rather than soil factors such as the presence of more reactive substances. In all the samples of polysulphide tested, both from different soil fractions and from commercial sources, the relationship between polysulphide oxidized and time has been a logarithmic one such that:

$$\mathrm{Fe} = k.\ \log.\ t \times c$$

where Fe represents the amount of polysulphide oxidized, t the time and k and c are constants. Evidence has been obtained which shows that a similar relationship governs the formation of elemental sulphur from pyrite in soil. In terms of oxidation of soil pyrite, this means that oxidation in the early stages of aeration is rapid, but that it falls off according to the logarithmic law so that oxidation is complete only after a much longer time. Thus, to give an example from some actual results, an oxidation in which a quarter of the polysulphide was decomposed in eight hours took thirty-six hours for the oxidation of half of it and over a thousand hours for the oxidation to reach completion. It is this relationship which is responsible for the observations that pyrites may sometimes be stable to oxidation and at other times rapidly decomposed, and it is likely to be of importance in the reclamation of mangrove soils and possibly other types of acid-sulphate soil in other parts of the world. The practical implications of the work will be discussed later.

It is possible to explain the logarithmic relationship obtained for pyrites oxidation on the basis of the existence of the material in soil as sparingly soluble particles. An equation has been derived which describes the decomposition of a single spherical pyrites particle and it has been shown that this function approaches linearity when plotted against log. time over much of the range of t. The equation derived for the oxidation of a single spherical particle does not fit the experimental results exactly, but it has been shown that the deviation from the predicted results can be explained, on the basis of the distribution of particle sizes in the soil polysulphide. The kind of distribution of particle sizes which would be expected in soil is one in which a large proportion of the material is present in the form of relatively small particles. This type of distribution

has been shown experimentally to be present in a sample of purified pyrites and by combining the rate of decomposition calculated from the equation with the estimate obtained of the distribution of the different particle sizes it has been possible to obtain a composite rate of decomposition which approaches that shown by experiment.

It has been concluded that it is now possible to explain the observed behaviour of soil polysulphides on the basis of their presence in soil as particles and on the expected distribution of these particles. Knowledge is therefore now available of the way in which the three main types of soil sulphur compound are oxidized in soil and the conditions under which acid may be formed from them.

Field Experiments

The experimental empoldering scheme at Wellington has been visited at regular intervals throughout the year and soil samples collected and brought to the laboratory for analysis. Three independent empolders were constructed* and were completed in April 1960. In July, one empolder was enclosed to prevent inflow of tidal water. The others were left under tidal conditions to determine whether improved drainage alone would be effective in reducing the concentration of oxidizable sulphur compounds in the soil during the rainy season. No such reduction has been observed; the total oxidizable sulphur content of the soil in these polders remained at the same level throughout. A slight increase in the elemental sulphur content of the soil was observed but the soil pyrite remained substantially unchanged. This result was in accordance with the laboratory experiments already discussed. One of these empolders was enclosed in February, 1961. The other has been left open throughout and is to be used in the coming growing season for a trial of salt-resistant and short duration rices.

The empolder which was enclosed developed highly acid conditions towards the end of the rainy season—oxidation of sulphur compounds has been followed by analyses and has been shown to occur in the same way as predicted from laboratory experiments. At the end of April, 1961, the polder was divided into two blocks. One remained enclosed and the other was opened to tidal influence in order to attempt the removal of acid compounds by washing with sea water. The results will be reported in more detail at a later stage, when data from proposed experiments with transplanted rice are available.

Practical Implications of Reclamation Procedures

From the practical point of view, the implications of the results may be of importance in the reclamation of various types of acid sulphate soil. The problem in Sierra Leone and other parts of West Africa is to devise a method of removing the acid compounds as cheaply as possible. Liming is prohibitively expensive, and the deposits are low in calcium. Removal of acid compounds by leaching with rain water is a slow process. A method which is now being tried on a field scale at Wellington is as follows—mangrove land is cleared and empoldered to exclude tidal water. A drainage system based on the natural creek drainage of the area is constructed. During the dry season the soil is allowed to dry and oxidation of sulphur compounds occurs. An attempt is then made to remove the acid formed together with its associated salts by re-establishing tidal conditions

* Grateful acknowledgement is made of the generous help of Mr. D. S. Garvie, O.B.E., and his staff of the Irrigation and Drainage Branch of the Department of Agriculture, Sierra Leone, who were responsible for the construction of these polders.

and leaching with salt water. When the removal of the oxidized substances has ceased, tidal wash is permanently excluded and sea salt is removed by leaching with rain water. The use of lime at this stage will probably be necessary for the removal of residual toxicities and possibly to hasten leaching of sea salt by improving structure, though this is not normally a serious problem when such soils are reclaimed for rice. At present the experiments are only in their early stages and will be reported more fully later, but it is of interest to examine the possibility of success of the proposed method in view of the laboratory results obtained.

In practice, the length of time taken for the complete oxidation of the soil polysulphides would be longer than that taken in laboratory experiments and even though the soil acidity were intense, about half of the oxidizable sulphur would be likely to remain unoxidized at the end of the first season. If soil polysulphides were oxidized at a uniform rate, this residuum of unoxidized material could be the source of embarrassment in future years, and a recurrence of the problem, involving expensive dressings of liming materials, might occur. However, the results obtained indicate that residual pyrites would become oxidized only very slowly under prevailing conditions and, once the soil acidity had been brought to a suitable level for rice production, it is likely that their rate of disappearance would be negligible. The proposed method—elimination of the soil polysulphides by oxidation and leaching, followed by elimination of residual toxicity and establishment of a suitable soil reaction would seem to be in accord with the facts available.

In acid sulphate soils isolated from tidal action this method of reclamation might not be applicable, as sufficiently powerful leaching action could not be brought to bear on the soil. In this case, if the sulphur in the soil were present as ferrous sulphide or elemental sulphur, a policy of complete neutralization would have to be adopted and the costs of any contemplated scheme calculated on this basis. However, if the predominant sulphur compound was polysulphide, successful attempts to prevent the oxidation of as large a fraction as possible might be made. Given a logarithmic relationship for the rate of decomposition of the soil polysulphides a policy of seasonal liming of such soils would be theoretically correct. The surface-area/volume ratio of the polysulphides would be expected to decrease from year to year until the rate of decomposition of the remaining fraction would be so slow that it could be neglected, providing the soil was not allowed to become acid. The annual dressing of lime required would thus be reduced. The total lime requirement of such a soil might be considerably less than that calculated on the basis of its total content of oxidizable sulphur, and it seems likely that an oxidation method would be of greater value in accessing the practical lime requirement of such soils.

Phosphorus fixation

Phosphorus is one of the most essential fertilizer requirements of soils in West Africa and has been reported as being the limiting factor in the fertilization of mangrove soils. As mentioned in last year's report, it is now considered that nitrogen, not phosphorus, may be limiting, but nevertheless a considerable response to phosphorus application has been obtained.

The acidity produced in empoldered, coastal swamps liberates iron and aluminium and the poor growth of rice in the polders has been attributed, amongst other things, to these ions. It is generally accepted that much of the beneficial effect of applied phosphate to soils is often due to fixation of aluminium but during an examination of mud from a mangrove swamp

it was found that, despite a high (5 per cent) dilute acid-extractable aluminium content, there was practically no aluminium-bound phosphorus; this was true even in cases where added calcium phosphate had been immobilized in the mud. This finding led to a detailed investigation into the phosphorus relationships existing in the muds, the fate of added phosphorus and the effect of drying the mud upon phosphorus distribution.

It was found that 87 per cent of the total phosphorus was in organic combination and that the remainder was almost entirely in association with iron and calcium. The swamp muds are comparatively unweathered and thus contain hardly any occluded forms of phosphorus.

The results of incubation experiments have shown that inorganic phosphorus mineralized from the organic fraction appears in association with iron and, to a lesser extent, with calcium, but never as aluminium phosphate. The only time aluminium phosphate increased in concentration was when the muds were incubated aerobically with added calcium carbonate.

The fixation of inorganic phosphorus by the fresh and dried muds is an extremely rapid process. Equilibrium was almost attained within thirty minutes and considerable fixation occurred within five minutes. The difference in amount of phosphorus fixed in thirty minutes and thirty days was negligible.

The changes in forms of phosphorus were followed by analysis during the time that the muds were in contact with excess available phosphorus and a similar investigation was made using muds washed free from excess soluble phosphorus after twenty-four hours of contact. In every case where excess soluble phosphorus was not continuously present there occurred a loss of aluminium phosphate with time, whereas iron phosphate increased in concentration. In the presence of excess soluble phosphorus the iron and aluminium phosphates remained constant in amount after their initial increase.

When calcium phosphate was added to the mud at the lower and more practical rate of 40 parts per million of phosphorus, the aluminium phosphate, after an initial increase, decreased again within thirty days to its original low value.

The absence of aluminium-bound phosphorus in the mangrove swamp muds appears therefore to be due to a transfer to iron of any phosphorus which may have been acquired by aluminium.

Figures reported from British Guiana show very high contents of soluble aluminium in the coastal swamps, and often this aluminium has proved to be non-toxic to rice crops. It would now appear that, in the corresponding swamps in Sierra Leone, the beneficial effect of phosphorus fertilizers is probably not due to fixation of aluminium ions and thus it is possible that the aluminium in coastal swamps is in some form non-toxic to plants.

Further studies of the phosphorus relationships and forms of aluminium in the mangrove swamps are being made.

Nigerian Swamp Soils

A number of samples of soils from Nigerian coastal swamps have been collected and briefly examined. A few notes on these are given.

The soil of the Adani flood plain in Eastern region is very poor in organic matter and appears to have practically no organic-phosphorus at all. Organic phosphorus is most important as being the source of readily available phosphorus and a response to phosphorus fertilizers could be expected in this region. Similarly a response to nitrogen would be expected.

The soils from Calabar, Mpiabaka and Warri are very similar except that Calabar soil appears to be poorer in calcium content. All the muds

go very acid when dried and are sulphidic. No liberation of available nitrogen was observed when the muds were dried and thus a large response to nitrogen fertilizers would be expected—and indeed this is the case.

INVESTIGATIONS INTO THE CHEMISTRY AND FERTILITY OF RICE SOILS

In continuation of laboratory and experimental work on the state of reduction of rice soils, which was reported previously, further experiments in which rice was grown in buckets were carried out. Three different soils have now been used and high replication has been possible. In no case has any increase in yield been found from any depth of standing water as compared with 100 per cent water holding capacity; with one of the soils the highest yields were obtained from treatments with water at 90 per cent field capacity. Measurements of acidity (pH) and of the oxidation-reduction potential (Eh) were made and the conclusion has been drawn that there is no justification for the practice of adjusting field Eh measurements for pH change. It is doubtful if the direct measurement of the Eh of paddy soils in the field can yield any useful information.

The ferrous iron contents of acid extracts of these soils were determined and dichromate titrations performed; ferrous iron was the only reducing substance found. Available nitrate nitrogen and ammonium nitrogen were determined at various stages during the growing period. The results, when compared with yields, suggest that the previous definition of "Healthy Reducing Conditions" is insufficiently sensitive to give useful information about normal paddy soils and that a further definition of "Optimum Reducing Conditions" needs to be made. This will probably be at the upper limit of "Healthy Reducing Conditions" and may be a function of the rate of supply of available nitrogen. Trials are in progress on the experimental growth of short-duration and photoperiod-insensitive rices in the dry season by artificial irrigation, and this approach should be of direct value in determining the best method of use of the available water from the soil fertility point of view.

The trials laid down last year on the marginal land at Rokupr and on the station extension areas at Mando and Kontobe, and which compared applications of three levels of lime and four of superphosphate, were again planted to determine residual effects. No significance was seen in the Mando experiments, but, in the other two the residual effects from the lime were twice the first year effects and there were considerable residual effects from superphosphate at Kontobe. A complete repetition of the experiment on another area at Kontobe was damaged by antelope and showed no significant difference in yields.

Residual effects were also examined at Rokupr and Kontobe of last year's factorial trials where iron-rich soil, superphosphate, lime and organic matter were added. Additional organic matter was added to these trials this year, and it gave very large yield increases at both sites; the lime and phosphate effects agreed closely with the other experiments. A repetition of the experiment at Rokupr on a less fertile site showed a significant effect of lime, but a repetition at Kontobe suffered antelope damage and gave no information.

A further experiment on more fertile land at Rokupr showed no significant effects from phosphorus and nitrogen, though a similar one at Kontobe with broadcast rice showed a depressant effect of nitrogen.

A subtractive field experiment was also carried out at Kontobe and the only significant difference in yield was that found when the total nutrient was omitted. The experiment was carried out on land which had received a superphosphate application in the previous year and the residual effect of this may account for the discrepancy with last year's bucket trial on

similar soil, where the omission of phosphorus caused equal diminution in yield to that of the omission of total nutrient.

At Kontobe a further experiment was carried out in which time and method of application of nitrogen and further application of a top dressing were investigated on both broadcast and transplanted rice. Owing to lack of soil uniformity no significance was shown but the depressant effect of late nitrogen application was very noticeable and almost significant.

Results at Kontobe so far suggest that early application of nitrogen, digging the resultant weed growth in and transplanting the rice may be the way to produce worthwhile yields. The lime and phosphate requirements are easy to supply but it is probably true to say that the very low nitrogen content of the soil has limited growth in all experiments so far; the effect of added organic matter supports this.

Three trials were also carried out on upland rice on a typical upland farm of the Rokupr area. These compared applications of major mineral nutrients, lime and organic matter but soil uniformity was very poor and no significant results were obtained.

Yield figures of interest from these experiments are given in Appendix B.

APPENDIX A

METEOROLOGICAL RECORDS ROKUPR—1960

	Jan.	*Feb.*	*March*	*April*	*May*	*June*	*July*	*Aug.*	*Sept.*	*Oct.*	*Nov.*	*Dec.*	*Year*
Rainfall (25 year average)	0·00 (0·19)	0·00 (0·05)	0·00 (0·54)	0·40 (2·33)	7·95 (7·06)	17·27 (14·60)	26·46 (23·58)	24·17 (28·89)	22·88 (18·40)	12·76 (14·28)	3·37 (6·16)	0·09 (0·87)	115·35 (116·95)
Sunshine (20 year average)	239·3 (249·2)	219·3 (227·5)	263·2 (241·7)	241·6 (208·4)	196·4 (191·4)	184·5 (158·7)	111·8 (101·3)	75·4 (65·2)	114·8 (121·7)	217·0 (199·4)	207·4 (193·4)	237·9 (224·3)	2308·6 (2182·2)
Mean Maximum Temperature (20 year average)	91·8 (90·9)	91·7 (92·8)	91·6 (93·0)	91·6 (92·7)	89·9 (90·8)	86·6 (87·7)	84·4 (83·8)	82·7 (81·9)	84·2 (85·4)	87·7 (88·0)	88·6 (88·7)	89·6 (89·1)	88·4 (88·6)
Absolute Maximum Temperature (20 year record)	97 (102)	96 (101)	— (102)	96 (103)	93 (101)	91 (99)	93 (98)	87 (91)	90 (99)	91 (96)	91 (99)	92 (97)	97 (103)
Mean Minimum Temperature (20 year average)	66·3 (68·3)	70·2 (69·7)	70·4 (71·6)	71·9 (73·0)	72·6 (73·5)	72·2 (72·4)	71·9 (72·1)	72·9 (72·0)	72·1 (72·3)	70·8 (71·7)	71·2 (71·8)	70·2 (69·5)	71·1 (71·5)
Absolute Minimum Temperature (20 year record)	59 (50)	64 (60)	68 (62)	68 (65)	69 (69)	69 (63)	69 (60)	71 (67)	70 (68)	68 (68)	67 (63)	57 (53)	57 (50)
Mean Relative Humidity a.m. (10 year average)	89 (88)	88 (87)	83 (84)	80 (82)	86 (84)	88 (89)	90 (92)	92 (93)	91 (92)	86 (89)	84 (89)	81 (88)	87 (88)
Maximum Relative Humidity a.m. (10 year record)	96 (100)	94 (100)	90 (100)	93 (100)	95 (100)	96 (100)	97 (100)	97 (100)	97 (100)	98 (100)	99 (100)	96 (100)	99 (100)
Mean Relative Humidity p.m. (10 year average)	60 (53)	52 (48)	49 (52)	55 (54)	65 (65)	74 (73)	81 (81)	86 (83)	— (80)	69 (71)	74 (68)	55 (57)	68 (65)
Minimum Relative Humidity p.m. (20 year record)	25 (16)	19 (14)	33 (23)	42 (31)	49 (31)	59 (54)	59 (59)	70 (53)	68 (51)	60 (41)	47 (37)	20 (10)	19 (10)

Rainfall in inches. Sunshine in hours. Temperature in degrees Fahrenheit. Relative Humidity as percentages. Morning readings taken at 09.00 hours. Afternoon readings taken at 15.00 hours. Bracketed figures are averages and records. March maximum temperatures and September afternoon humidities incomplete.

APPENDIX B

RESULTS OF FERTILIZER TRIALS

(a) *Residual effects of phosphate and lime at Rokupr*

Layout Randomized Block 6 replications.

Treatments Superphosphate (P) at 0, 1, 2 and 3 cwt./acre, Lime (L) at 0, 2 and 4 tons/acre, applied in 1959.

Variety Radin China 4.

Plots 12 × 12 feet.

Area of plot harvested ·0033 acre.

Yields in lb./acre

Lime \ *Phosphate*	P_0	P_1	P_2	P_3	*Mean*
		Standard error ± 108			*S.E.* ± 54
L_0	1120	1219	1185	1329	1213
L_1	1405	1427	1283	1471	1396
L_2	1500	1398	1736	1660	1573
Mean	1342	1348	1401	1486	1394
		Standard error ± 63			

Coefficient of variation 19%

(b) *Residual effects of phosphate and lime at Kontobe*

Layout Randomized Block 6 replications.

Treatments Superphosphate (P) at 0, 1, 2 and 3 cwt./acre, Lime (L) at 0, 2 and 4 tons/acre, applied in 1959.

Variety Parn A-191.

Plots 12 × 12 feet.
Area of plot harvested ·0033 acre.

Yields in lb./acre

Lime \ *Phosphate*	P_0	P_1	P_2	P_3	*Mean*
		Standard error ±56			*S.E.* ± 28
L_0	113	229	333	303	245
L_1	303	431	447	516	424
L_2	443	606	704	610	591
Mean	286	422	495	476	420
		Standard error ± 33			

Coefficient of variation 32%

(c) *Method of application of nitrogen at Kontobe*

Layout Randomized Block 8 replications.

Treatments Broadcast (B) and Transplanted (T) rice; Sulphate of ammonia at 2 cwt./acre applied at date of sowing (E), at date of transplanting (L) and in mud balls (M); top dressing (TD) of 2 cwt./acre sulphate of ammonia applied to half plots; basic dressing of 3 cwt./acre superphosphate and 2 cwt./acre potash applied throughout.

Variety Parn A-191.

Plots 12 × 12 feet.

Area of plot harvested ·0033 acre.

Yields in lb./acre

Application / *Method*	*Nil*	*E*	*L*	*M*	*Mean*
T TD_0	788	1099	741	840	867
T TD_1	854	802	689	925	817
Mean T	821	951	715	882	842
B TD_0	580	590	552	750	618
B TD_1	623	541	378	684	544
Mean B	602	540	465	717	581
Mean TD_0	684	845	646	795	742
Mean TD_1	738	646	533	804	681
Mean methods	711	745	590	780	712
		Standard error ± 58			

Coefficient of variation 32%